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(54) **Self-oscillating switching power supply with output voltage regulated from the primary side**

(57) Regulation of the output voltage of a power supply employing a flyback-type self-oscillating DC-DC converter employing a transformer is implemented in the circuit of the primary winding of the transformer by realizing a current recirculation loop for discharging the energy cyclically stored in an auxiliary winding of the self-oscillation loop of the converter such as to repre- sent a replica of the circuit of the secondary winding of the transformer and by summing a signal representative of the level of the energy stored in the auxiliary winding with a drive signal on a control node of a driver of the power switch of the converter.
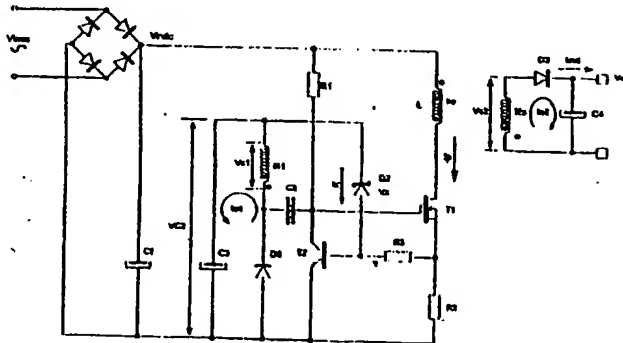
FIG. 2

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FCS0001234

Description

Switching power supplies offer remarkable advantages in terms of volume, weight and electrical efficiency if compared with traditional transformer-type power supplies functioning at the mains frequency. However, due to the complexity of the electronic circuitry employed, these switching power supplies are rather costly. One of the architectures most frequently used is based on the use of a flyback-type, DC-DC converter.

In a flyback system, energy is stored within the primary winding inductance of the transformer during a conduction phase of a power transistor (switch), functionally connected in series with the primary winding and is transferred to the secondary winding of the transformer during a subsequent phase of non-conduction of the switch, which is driven at a relatively high frequency (in the order of tens of kHz) for example by a local oscillator.

In switching power supplies, the voltage at the input of the DC-DC converter is not regulated. Commonly, in a power supply connectable to the mains, the input voltage of the converter is a nonregulated voltage as obtained by rectifying the mains voltage by a Wien bridge and leveling it by a filtering capacitor. Therefore this voltage is a nonregulated DC voltage whose value depends on the mains voltage that can vary from 180VAC to 264VAC in Europe and from 90VAC to 130VAC in America.

A basic diagram of a flyback-type, self-oscillating primary side circuit of a power supply connectable to the mains is shown in Fig.1.

At the turning on instant, the voltage V_{INDC} produces a current i in the resistance R1 that has normally a high ohmic value. This current charges the gate-source capacitance of the power switch T1, which, in the example shown, is an isolated-gate, field effect transistor. The gate-source voltage increases in time according to the following approximate equation:

$$V_{GS} = \frac{i \cdot t}{C_{GS}}$$

where V_{GS} indicates the voltage between the gate and the source of transistor T1, C_{GS} is the gate-source capacitance, i is the current that flows through R1 and t is time.

When the voltage V_{GS} reaches the threshold value V_{THR}, the transistor begins to drive a current I_p while the drain voltage V_{DS} decreases because of the voltage drop provoked by the current I_p on the inductance L of the primary winding N_p of the transformer.

Therefore, a voltage equal to V_{INDC}-V_{DS} is generated at the terminals of the primary winding N_p. This voltage, reduced according to the turn ratio N_1/N_p between the primary winding N_p and the auxiliary winding N_1 belonging to the self-oscillating circuit, is also applied between the gate node G and the common

ground node of the circuit through a capacitor C2. This voltage, which is in phase with the voltage present on the primary winding N_p provokes a further increase of the voltage between the G gate node G and the source node S of the transistor T1, which therefore is driven to a state of full conduction. Therefore the voltage on the inductance L of the primary winding N_p is approximately equal to the rectified input voltage V_{INDC} and the current that flows through the primary winding of the transformer has a value given by the following equation:

$$I_p = \frac{V_{INDC} \cdot t}{L}$$

On the other hand, the current I_p also flows in the resistance R2 provoking a voltage drop thereon given by $I_p \cdot R2$. Even this voltage drop grows linearly in time until it reaches conduction threshold value V_{BE} of the second (transistor) switch T2.

By entering into a state of conduction, the transistor T2 shortcircuits toward the ground node the gate node G of the transistor T1, which therefore turns off. Initially the current I_p continues to flow thus increasing the voltage V_{DS} well above the input voltage V_{INDC}. Therefore, a flyback voltage develops on the primary winding inductance L that has an opposite polarity to that of the voltage present during a conduction phase of the switch T1. This flyback voltage, reduced in terms of the turn ratio N_1/N_p, is also applied between the gate node G of the transistor T1 and the common ground node of the circuit and further contributes to keep the transistor T1 in an off condition, having a negative polarity as referred to the ground potential.

During a conduction phase of the transistor T1, the energy accumulated in the inductance L of the primary winding of the transformer transfers completely into the secondary circuit that is only partially depicted in the figure. This occurs during such an OFF (or FLYBACK) phase of operation of the transistor T1. When this phase of energy transfer is over, the voltage on the primary winding N_p and on the winding N_1 of the self-oscillating circuit are null and therefore a new cycle can start again.

The above mentioned system typifies a common flyback architecture where the primary current I_p rises linearly from zero up to a peak value given by the following equation:

$$I_p = \frac{V_{BE}}{R_2} \qquad (1)$$

during a conduction phase of transistor T1.

The relevant waveforms of the circuit are shown in Fig. 3.

Upon a variation of the input voltage V_{INDC}, the conduction time T_{ON} of transistor T1 varies according to the following expression:

$$T_{ON} = \frac{L \cdot V_{BE}}{V_{NDC} \cdot R_2} = \frac{L \cdot I_P}{V_{NDC}} \qquad (2)$$

Therefore, the frequency of oscillation is inversely proportional to the rectified mains voltage.

In the majority of applications, the output voltage must be regulated to make it independent from input voltage variation, in other words from the value of the rectified mains voltage.

Commonly in the majority of applications, control of the output voltage is implemented in the secondary circuit. These regulating use feedback control loops that normally sense the secondary voltage level and provide this information to the primary circuit via an electrical isolation device, for example a photo-coupler. These solutions, are very efficient but they are also relatively expensive. Even alternative known solutions implementing an output voltage regulation by regulating the current flowing through the primary winding of the transformer during conduction phase of the switch, imply the realization of one or more auxiliary windings and a remarkable complication of the primary circuit.

It has now been found a surprisingly simple and effective system for regulating the output voltage through the primary circuit of the transformer of a DC-DC converter. The system of this invention does not require any additional winding because it exploits the auxiliary winding N_1 of the self-oscillation circuit for implementing the desired regulation of the voltage output by the secondary circuit of the transformer-type converter.

In practice, the method of this invention consists in realizing a discharge current circulation loop of the energy transferred in the auxiliary winding of the self-oscillation circuit during a phase of conduction of the transistor that switches the primary winding and in summing a signal representative of the level of said energy on the control node of a driving stage of the switch to regulate its conduction interval.

Practically, the circulation loop of the discharge current relative to the energy stored in the auxiliary winding of the self-oscillation circuit, reproduces electrically the discharge current circulation loop of the energy that is stored in the secondary winding of the transformer. Through a process of self-redistribution of the energy that is stored in the primary winding inductance during the conduction phase of the switch, the system regulates the energy that is transferred from the primary to the secondary winding of the transformer so as to keep substantially uniform the output voltage (that is, the voltage that develops on the secondary winding of the transformer). This regulation occurs following a change of the value of the nonregulated input voltage and/or of the current absorbed by the secondary circuit.

The auxiliary winding of the self-oscillation circuit is in phase with the primary winding of the transformer during the switch conduction phase while is in phase with the secondary winding during the following off

phase of the switch (flyback phase).

According to an important embodiment of this invention, a power supply includes a self-oscillating DC-DC converter having a power switch (transistor) connected in series with a primary winding of a transformer that is coupled to an input voltage, and a sensing resistance functionally connected between the switch and a common potential node of the circuit. The switch is driven by a self-oscillating circuit composed of at least an auxiliary winding, magnetically coupled to the primary winding, and a first capacitor that are connectable in series between a control node of the switch and said common potential node. A second (transistor) switch is driven to shortcircuit the control node of the first switch with said common potential node, when the current flowing through the primary winding reaches a pre-established level. According to the invention, the circuit includes also a second capacitor connected between the auxiliary winding and said common potential node and at least a diode having the anode coupled to said common potential node and a cathode coupled to the intermediate connection node between the auxiliary winding and the first capacitor so as to constitute a discharge current recirculation loop for the energy stored in the auxiliary winding inductance, and at least a zener diode functionally connected between the intermediate connection node between the auxiliary winding and the second capacitor and a control node of the second (transistor) switch.

While the current recirculation loop realizes a replica in the primary circuit of the current recirculation loop of the secondary winding of the transformer, by means of the zener diode, a current signal is injected on the control node of the switch connected in series with the primary winding of the transformer so as to regulate the timing of the turning off of the switch by the driver stage thereof (that is, the interval of conduction of the switch). Through a mechanism of energy self-redistribution, the circuit ensures stability of the voltage, output by the secondary circuit of the converter, when the input voltage and/or the current absorbed from the secondary circuit change, as it will be further demonstrated in the description below.

The various aspects and advantages of this invention will become more evident through the following description of some important, though nonlimitative embodiments and by referring to the annexed drawings, wherein:

Figure 1 shows, as already mentioned above, a basic scheme of a self-oscillating primary circuit;
Figure 2 shows a basic scheme of a power supply connectable to the mains that employs a self-oscillating, flyback-type DC-DC converter made according to this invention;
Figure 3 shows, as already mentioned above, the typical waveforms of the flyback converter.

With reference to the diagram of Fig. 2 and to the

waveforms shown in Fig. 3, during a phase of operation where the transistor T1 conducts (T_{ON}). the voltage between the cathode of the diode D1 and the ground node of the circuit is positive and therefore the diode is not conductive and said positive voltage contributes to keep the transistor T1 in a state of conduction by means of the capacitor C2.

During the subsequent flyback phase, when the transistor T1 is not conductive, the voltage on the diode D1 cathode becomes negative and a recirculation current I_{S1} can circulate in the loop composed of the diode D1, the winding N1 and the capacitor C3. Therefore, the capacitor C3 is charged by the recirculation current I_{S1} and the voltage on it rises. By calling V_Z the voltage of the zener diode D2, when the following condition is fulfilled:

$$V_{C3} = V_Z + V_{BE} \qquad (3)$$

the diode D2 begins to conduct, thus forcing a current through the resistance R3.

By calling i_z the current that flows through the diode D2, the equation of the recirculation loop that includes the base-emitter junction of the transistor D2 and the resistances R2 and R3 becomes:

$$V_{BE} = i_z \cdot R_3 + I_P \cdot R_2 \text{ for } R_3 \gg R_2 \qquad (4)$$

If i_z increases due to an increment of the voltage V_{C3} reached by the capacitor C3 when charging, I_p and consequently T_{ON} must proportionally decrease in value in accordance with equation (2). Therefore, a lower amount of energy will be stored in the inductance L of the primary winding of the transformer and, as a consequence, a lower recirculation current I_{S1} will flow during the next flyback phase in order to keep the voltage V_{C3} constant and equal to a value given by $V_Z + V_{BE}$. Thus, during a flyback phase, the voltage applied to the N1 winding is constant and equal to:

$$V_{S1} = V_{C3} + V_{D1} \qquad (5)$$

where V_{D1} represent the voltage drop through the diode D1 when conducting.

Even the voltage v_{s2} that develops on the secondary winding N_S of the transformer will be constant during the flyback phase and will have a value given by:

$$\frac{V_{S2}}{V_{S1}} = \frac{N_S}{N_1} \qquad (6)$$

by combining equations (3), (5) and (6), we obtain:

$$V_{S2} = (V_Z + V_{BE} + V_{D1}) \cdot \frac{N_S}{N1} \qquad (7)$$

and the output voltage V_{OUT} becomes:

$$V_{OUT} = (V_2 + V_{BE} + V_{D1}) \cdot \frac{N_S}{N_1} \cdot V_{D3} \qquad (8)$$

where V_{D3} indicates the voltage drop on the diode D3 when conducting.

Equation (8) contains only constant terms therefore the resulting output voltage V_{OUT} will be constant too. In particular, if $N_2 = N_1$ and $V_{D1} = V_{D3}$, the output voltage becomes:

$$V_{OUT} = V_Z + V_{BE} = V_{C3} \qquad (9)$$

Therefore the above described circuit permits the regulation of the output voltage of the secondary side circuit of the transformer-type DC-DC converter by implementing the necessary control in the primary side circuit of the converter by the addition of only three components, namely: D1, D2 and C3, according to the embodiment shown.

In practice, by the addition of the components D1 and C3, a recirculation loop is realized for a discharge current of the energy stored in the auxiliary winding N1 of the self-oscillation circuit, which substantially replicates the secondary side output loop of the converter. By means of the zener diode D2, a current i_z is then injected on the driving node of the transistor T2, said current is representative of the charge level reached by the inductance of the auxiliary winding N1 of the self-oscillation circuit, during a phase of conduction of the switch D1. This current i_z produces a voltage drop on the resistance R3, which is in turn summed to the voltage drop $I_p \cdot R2$ during the conduction phase of the switch T1, thus regulating the turn-on interval T_{ON} and therefore the energy stored in the inductance L of the primary winding of the transformer.

The system is perfectly capable of regulating the output voltage V_{OUT} upon the changing of the input voltage V_{INDC} as well as of the output current I_{OUT}.

In fact, if the output current increases, a larger amount of energy must be transferred from the primary winding N_p to the secondary winding N_S during the flyback phase so that a lower amount of energy remains available from the inductance of the auxiliary winding N1 to charge the capacitor C3. Therefore the voltage reached by C3 upon charging will be lower. As a consequence, the current i_z will also be lower and the current I_p will proportionally increase in order to fulfill the following equation:

$$V_{BE} = i_z \cdot R_3 + I_P \cdot R_2 \text{ for } R_3 \gg R_2$$

The increase of the current I_p increments the energy stored in the inductance L of the primary winding N_p and this increased energy will be available during the flyback phase. Therefore the system is capable to supply the additional energy required by the rise of the output current I_{OUT}, thus keeping constant the output voltage V_{OUT}.

The way the increase of the output current I_{OUT} pro-

vokes an increase of the conduction interval (T_{ON}) of the switch T1 (and therefore a consequent reduction of the converter switching frequency) to allow the current I_p to reach a higher peak value should be remarked.

Claims

1. Method for regulating the output voltage of a power supply employing a flyback-type DC-DC transformer converter wherein the primary winding of the transformer is driven by a switch controlled by a self-oscillating circuit that comprises an auxiliary winding magnetically coupled to said primary winding, and characterized in that comprises

> realizing a recirculation loop for a discharge current of the energy cyclically stored in said auxiliary winding during a nonconduction phase of the switch, replica of the current loop of the circuit of the secondary winding of the transformer;
> summing a signal representative of the level of the energy stored in said auxiliary winding with a drive signal on the control node of a driver stage of said switch.

2. A method according to claim 1, characterized in that said auxiliary winding is in-phase with the transformer primary winding during a phase of conduction of the switch and in-phase with the secondary winding of the transformer during a phase of nonconduction of the switch or flyback phase.

3. A self-oscillating, DC-DC converter comprising a transformer's primary winding side circuit and a transformer's secondary winding side circuit, said primary circuit comprising a first switch, functionally connected in series with the primary winding of the transformer, which is coupled to an input node, and a sensing resistance functionally connected between said first switch and a common potential node of the circuit, said first switch being driven by a self-oscillation circuit composed of at least an auxiliary winding magnetically coupled to said primary winding and a first capacitor connected in series between a control node of said first switch and said common potential node and a second switch capable of shortcircuiting said control node with said common potential node when the current through the primary winding reaches a pre-established level, characterized in that comprises

> at least a second capacitor connected between said auxiliary winding and said common potential node;
> at least a diode having an anode coupled to said common potential and a cathode coupled to an intermediate connection node between said auxiliary winding and said first capacitor;

and
> at least a zener diode connected between said intermediate node and a control node of said second switch.

4. A flyback-type power supply connectable to the mains having means for regulating the output voltage in the primary side circuit of the transformer of the power supply, characterized in that comprises a self-oscillating DC-DC converter as defined in claim 3.

5. A power supply according to claim 4, characterized in that said first switch is an isolated-gate, field effect device and said second switch is a bipolar NPN transistor.
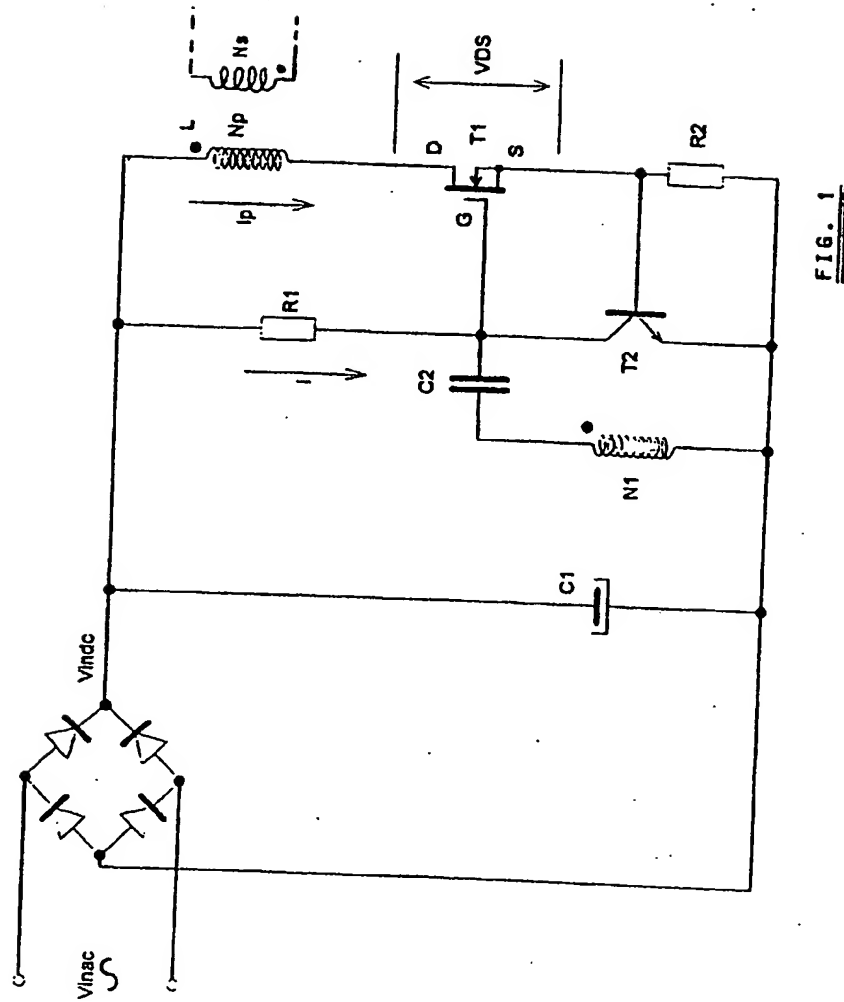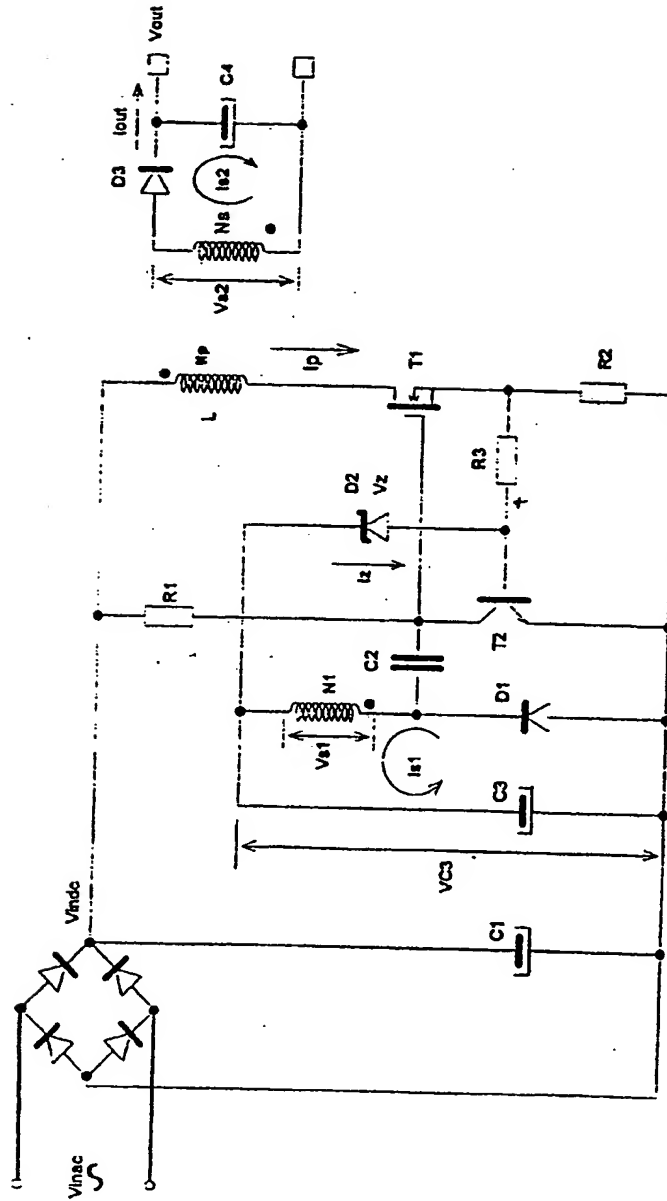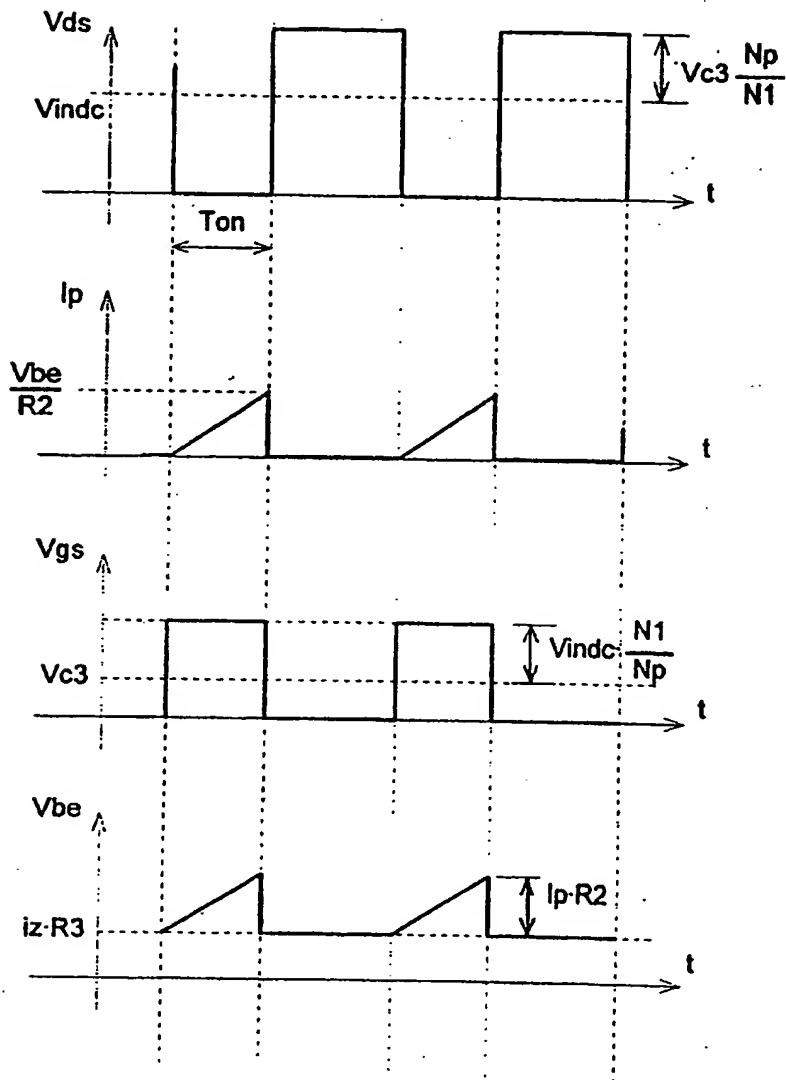
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FIG. 1

FIG. 2

FCS0001240

Vds

Vindc

$Vc3 \dfrac{Np}{N1}$

Ton

t

Ip

$\dfrac{Vbe}{R2}$

t

Vgs

Vc3

$Vindc \dfrac{N1}{Np}$

t

Vbe

iz·R3

Ip·R2

t

FIG. 3

8

FCS0001241

Europeaan Patent
Office

EUROPEAN SEARCH REPORT

Application Number

EP 95 83 0235

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US-A-5 369 307 (KOBAYASHI TADASHI) 29 November 1994 * column 2, line 36 - line 43; figure 2 *	1,2	H02M3/00 H02M3/338
X	PATENT ABSTRACTS OF JAPAN vol. 017 no. 230 (E-1361) ,11 May 1993 & JP-A-04 359673 (NEC CORP) 11 December 1992, * abstract *	1,2	
A	US-A-5 168 435 (KOBAYASHI TADASHI ET AL) 1 December 1992 * column 1, line 42 - line 53 *	3-5	

TECHNICAL FIELDS
SEARCHED (Int.Cl.6)

H02M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 December 1995	Van den Doel, J

FCS0001242